Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

A REVIEW OF THE ACTIVITIES OF THE MINERAL SCIENCES LABORATORIES IN PLASMA TECHNOLOGY IN THE PERIOD 1983-1989

S.A. Mikhail
Pyrometallurgy Section
Extractive Metallurgy Laboratory

June 1990

This document is an archival interim report prepared primarily for discussion and limited circulation. It does not represent a final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport intérimaire préparé et rédigé principalement pour un de discussion et de diffusion limitée. Il ne représente nullement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

Project: 30.95.01.0002
Planning and Review

MINERAL SCIENCES LABORATORIES
DIVISION REPORT MSL 90-59 (LS)

18 pp

Crown Copyright Reserved

MICROMEDIA

90-07118/

KEYWORDS

PLASMA TECHNOLOGY - PYROMETALLURGY - MSL CONTRACTS - INHOUSE RESEARCH - ENERGY RESEARCH AND DEVELOPMENT

A REVIEW OF THE ACTIVITIES OF THE MINERAL SCIENCES LABORATORIES IN PLASMA TECHNOLOGY IN THE PERIOD 1983-1989

S.A. Mikhail*

ABSTRACT

This report summarizes the research activities of the Mineral Sciences Laboratories (MSL) in the field of plasma technology. It includes a brief account of the nature of the involvement of MSL in this new field before 1983, of the inhouse research work and of the contract work sponsored by MSL and funded by the Panel on Energy, Research and Development in the period 1983-1989.

* Research Scientist, Pyrometallurgy Section, Mineral Sciences Laboratories, CANMET, Energy, Mines and Resources Canada, 555 Booth Street, Ottawa, Ontario K1A 0G1.

A REVIEW OF THE ACTIVITIES OF THE MINERAL SCIENCES LABORATORIES IN PLASMA TECHNOLOGY IN THE PERIOD 1983-1989

S.A. Mikhail

The plasma is a state of matter in which a gas is partially ionized as a result of the action of ultra high temperatures or a very strong electric or magnetic fields. A partially ionized gas composed of ions, electrons and neutral molecules provides an environment conducive to the promotion of reactions difficult to achieve under "normal" circumstances. For metallurgical and other high temperature applications, thermal plasma can be produced by creating an electric arc between two or more electrodes generating temperatures of several thousand degrees. Under such conditions, more reactive species are created, materials that require ultra high temperatures can be processed and improved reaction kinetics can be achieved.

In the last few years it has become evident that plasma technology, in many instances, has the potential for the efficient substitution of electrical energy for fossil fuel utilization as well as for completely new applications. It is also evident that plasma technology has developed to the state where applications on an industrial scale are being seriously considered, planned or a reality. Several countries including Germany, Sweden, Japan, France, Austria, Russia, South Africa and the United States have already passed the pilot plant stage and now in the process of developing full scale commercial metallurgical operations based on this technology.

The availability of excess supply of relatively inexpensive electric power in some Canadian provinces puts Canada in a favourable position to develop and use plasma technology. Despite the existence of some university and government research activities and test facilities, Canadian industries are hesitant to adopt the new technology and Canada lags behind in its development and applications.

The involvement of the Mineral Sciences Laboratories in the field of plasma technology before 1983 was limited to acquiring knowledge in the field and attending meetings with industries interested in the application of thermal plasma in their conventional processes or in the development of demonstration projects utilizing this technology. The following are some examples of applications that were proposed by industries subject to partial or complete government funding:

Enduration of iron ore pellets using plasma.

Iron Ore Company of Canada / Sidbec Normines

Using plasma torches as a heat source in the fluidized bed dryers of iron ore concentrate.

Wabush Mines / Westinghouse Canada

The reduction of coke consumption in the blast furnace by using plasma torches in the tuyeres.

Stelco / Dept of ITC

Processing of baghouse dust from iron foundries using thermal plasma.

Dominion Bridge

After 1983, MSL involvement in plasma technology was aimed at developing expertise in this field to assist in the transfer of the technology to interested Canadian industries and to provide advice on industrial initiatives seeking government funding. This was done by carrying out inhouse research and by sponsoring studies on the application of plasma technology in metallurgical processing in particular and on thermal plasma in general.

The Pyrometallurgy Section in MSL, CANMET, has undertaken an inhouse project involving the design, construction, testing and operating of a pilot scale 100kVA A.C. plasma reactor similar to that developed and operated for a few years at the University of Toronto. Retractable graphite electrodes with concentric holes for the introduction of plasma gas (argon), and magnesium oxide castable refractory lining were used in the reactor. The reactor was also equipped with a screw feeder for the raw materials capable of feeding rates of 10 kg/h or more. The feed was introduced through a top central port in a counter current with the rising gases.

The different operational parameters of the plasma reactor were studied and optimized. Smelting experiments were carried out on iron and chromite ores blended with coke and flux to examine the reducibility of these ores in a plasma reactor. In the reactor, estimated temperatures of over 1700°C were attained but the radiation losses to the walls and to of the reactor were high. The experiments with iron ore were satisfactory but, in most cases, the obtained metal contained substantial amounts of carbon and silicon (from the added flux). Moreover, excessive dissolution of the refractory lining in

the melt occurred. With the chromite ore smelting experiments, ferrochrome was obtained as a metallic phase containing some carbon and silicon. Losses of chromium and iron to the slag, however, were noticeably low.

Despite several difficulties encountered during the inhouse plasma project, the experience gained from operating the reactor will be very valuable in future plasma work as well as in the examination of external projects partially or completely funded by EMR.

The following is a brief description of individual MSL-awarded contracts in the field of plasma technology, with funds from the Energy Research and Development Program in the period 1983-1989.

TITLE: **Petroleum coke gasification in a plasma jet reactor**

CONTRACTOR: M. Boulos, University of Sherbrooke
SCIENTIFIC AUTHORITY: J.M. Skeaff
COST: $165,858
DURATION: Jul. 83 - May 85
REQN. No.: 3-9043

OBJECTIVE: Petroleum coke is a by-product of petroleum refining which contains a low level of volatile components and is not readily combusted. The objective of this contract was to determine whether petroleum coke could be gasified and reacted with hydrogen to produce recoverable hydrocarbons in the high temperature of a plasma jet reactor.

PROCEDURE: The investigators designed, built and operated a spouted bed plasma reactor in which petroleum coke was introduced with hydrogen. They determined the extent of hydrocarbon by monitoring the composition of the exit gas stream using gas chromatography.

RESULTS: The investigators found that relatively small amounts of CH_4 in the gas were produced in the spouted bed plasma reactor.

APPLICATION AND ONGOING WORK: Presentations were given on the development of the research work and the obtained results. The final results indicated that acetylene and ethylene were produced in the spouted bed plasma reactor, but in concentrations too low to make the process practical.

TITLE: **Survey of the potential of plasma technology application in Canada**

CONTRACTOR: J. Mikhlin, SNC Inc., Montréal.
SCIENTIFIC AUTHORITY: J.M. Skeaff
COST: $73,500
DURATION: Sept. 84 - Nov. 85
REQN. No.: 4-9010

OBJECTIVE: To identify industrial sectors and processes in Canada in which currently available plasma technology has potential application.

PROCEDURE: Discussions with various plasma systems manufacturers and representatives of appropriate industrial sectors, attendance at conferences, development of economic analysis, review of literature.

RESULTS: The most appropriate industrial sectors for plasma application in Canada are ferroalloys, refractory metals, melting-smelting, conversion of hydrocarbons to synthetic fuels and the synthesis of particulates for advanced ceramics.

APPLICATION AND ONGOING WORK: Technology transfer seminars, studies in some of the above areas.

TITLE: **Assessment of prospects for thermal plasma furnace technology.** A multi-client study

CONTRACTOR: D. Gold, Battelle Institute, Geneva.
SCIENTIFIC AUTHORITY: J.M. Skeaff
COST: $24,015
DURATION: Aug. 84 - Nov. 84
REQN. No.: 4-9051

OBJECTIVE: To identify the individual applications of plasma furnace technology which are the most likely candidates for industrial development, and evaluate their prospects on the basis of technical and economic criteria.

PROCEDURE: Discussions with scientists, suppliers, economists, potential and actual industrial users, and review of literature.

RESULTS: A five-volume report which concludes that plasma technology yields a broad spectrum of conventional products and offers definite advantages with respect to product purity.

APPLICATION AND ONGOING WORK: Related to SNC study on plasma opportunities in Canada.

TITLE: D.C. Plasma arc furnace

CONTRACTOR: R. Stratten-Crawley, INCO Limited, Toronto.
SCIENTIFIC AUTHORITY: J.M. Skeaff
COST (total to Crown): $460,000 (IRAP-NRC funds. INCO provided 2.3M of its own funding for the study. The Ontario Ministry of Energy contributed $130,000)
DURATION: Nov. 85 - Mar. 88
REQN. No.: 5-0870

OBJECTIVE: To investigate the production of utility nickel from the reduction of nickel oxide, the reduction smelting of roasted nickel concentrate and the production of nickeliferrous pig iron in a 900 kW DC plasma arc furnace and to use the resulting metallurgical and engineering design data for technical and economic feasibility studies for larger DC plasma arc furnaces at INCO locations in Canada.

PROCEDURE: The contractors designed, constructed and operated a 900 kW DC pilot plant ASEA design plasma arc furnace at their pilot plant facility in Port Colborne. They investigated the smelting of nickel metal carbonyl pellets, nickel oxide sinter, electrostatic precipitator dusts from the NiO roaster at Copper Cliff, $NiCO_3$ precipitate, and electrostatic precipitator dusts from the Ni converters at Copper Cliff.

RESULTS: A five-volume report detailing the results of their pilot plant investigations. One of their major findings was that their electrode consumptions were 50% higher for a conventional AC furnace, which is contrary to commercial operating experience to date with the ASEA design furnace. They also found that the DC furnace was better at treating EAF dusts that an AC furnace and is suitable for the treatment of high value, high quality products.

APPLICATION AND ONGOING WORK: To date INCO have not made any decision on implementing the technology on a commercial scale.

TITLE: **Investigations into the feasibility of direct reduction and smelting of sulphide ores in an LB furnace**

CONTRACTOR: W.-K. Lu, McMaster University, Hamilton
SCIENTIFIC AUTHORITY: J.M. Skeaff
COST: $70,044
DURATION: May 87 - May 88
REQN. No.: 6-9189

OBJECTIVE: To develop technology for the direct smelting of sulphide ores which will retain sulphur in the system for subsequent recovery in a form suitable for sale rather than release to the atmosphere as SO_2.

PROCEDURE AND RESULTS: The contractors reacted mixtures of chalcopyrite, coal, and lime or sodium carbonate at 950°C to obtain appr. 87% conversion of sulphide to CaS and Na_2S. Although they initially intended to separate the sulphide-bearing phases from lime, gangue and reduced copper and iron by plasma melting under water vapour to produce H_2S, this approach had to be abandoned because of the excessive amount of flux required and the high melting characteristics of CaS. Instead, they developed a flowsheet for producing reduced copper and iron as well as Na_2S from the reaction of sodium carbonate with chalcopyrite and carbon. The Na_2S is converted to H_2S and sodium bicarbonate from solution by reaction with CO_2 with the sodium bicarbonate then being converted to CO_2 and sodium carbonate for recycle.

APPLICATION AND ONGOING WORK: Since the funding on this contract has expired, the workers have developed a conceptual flowsheet based on the bisulphite anion to scrub low concentrations of SO_2 from process gas streams for which they are presently seeking funding.

TITLE: **The plasma production of titanium silicides and titanium-iron silicides**

CONTRACTOR: C.A. Pickles, Queen's University, Kingston and J.M. Toguri, University of Toronto
SCIENTIFIC AUTHORITY: C.A. Hamer
COST: $128.830
DURATION: Jan 88 - Mar 90
REQN. No.: 7-9196

OBJECTIVE: To conduct and investigation into the production of titanium silicide and titanium-iron silicides in a plasma reactor, and study the purity and physical properties of the produced silicide alloys and their oxidation behaviour.

PROCEDURE: A small plasma arc reactor was used to produce the silicides in graphite crucibles. Rutile powder was mixed with silica and metal reductant (Ca, Mg, Al) for the metalothermic reductions, or with carbon for the carbothermic reduction. Iron powder was used for the Ti-Fe-Si alloys.

RESULTS: Oxidation studies, including the effects of impurities, were conducted on the alloys. The phase diagrams were determined for the Fe-Ti and Ti-Si systems using the FACT system. Ti-Si can be produced as small particulates by aluminothermic reduction. Ti-Si crystals can be grown from a copper melt, with the copper being subsequently leached away. They exhibit excellent oxidation resistance. Iron and aluminium impurities increase the oxidation rates

APPLICATION AND ONGOING WORK: These silicides are of interest due to their corrosion resistance, refractory properties and hardness. This was an initial study into producing them by plasma. It would require

considerably more work and the participation of industrial partners before any commercial products could be realized.

TITLE: **Plasma Synthesis of ultrafine silicon carbide powders**

CONTRACTOR: M. Boulos, University of Sherbrooke
SCIENTIFIC AUTHORITY: S.A. Mikhail
COST: $ 150,000
DURATION: Oct. 87 - Sept. 89
REQN. No.: 7-9180

OBJECTIVE: To carry out a feasibility study on the synthesis of high-purity ultrafine silicon carbide powder using thermal plasma. The advantage of this technology is its ability to attain very high temperatures and to minimize the contamination and control the particle size of the product. It also offers the possibility of particle doping on a microstructure during the synthesis step which facilitate the subsequent sintering of the powder to near theoretical density bodies with superior mechanical and thermal properties.

PROCEDURE: The investigators designed, constructed and operated a plasma reactor with a d.c. plasma torch, gaseous hydrocarbon quench and low viscosity liquid hydrocarbon collection system. The procedure involved a direct reaction between vaporized elemental silicon and gaseous methane in the plasma region.

RESULTS: The study indicated that the synthesis of a SiC product, predominantly in the desirable beta form, with <4% free carbon and <2% free silicon is possible by using thermal plasma. The specific surface area of the ultrafine powder obtained was 49.4 m^2/g with a corresponding mean particle diameter of 39 nm.

APPLICATION AND ONGOING WORK: Alcan and Norton companies have shown

interest in the work but were reluctant to support it financially. The work is proceeding to a second phase where sintering of the powders will be examined.

CONCLUSIONS

This report is a brief overview of the inhouse and external activities of the Mineral Sciences Laboratories in the field of plasma technology in the period 1983-1989. The presence of university and government research activities and test facilities in Canada, and the excess supply of relatively inexpensive electric power in some provinces put Canada in a favourable position to develop and use plasma technology. MSL experience has shown, however, that Canadian industries are hesitant to use the new technology and Canada lags behind in its development and applications.

ACKNOWLEDGEMENTS

The author appreciates the assistance of J.M. Skeaff and C.A. Hamer in the Pyrometallurgy Section, MSL, CANMET, in providing information about CANMET contracts and inhouse work on plasma.